ODH in Lab E & F from LHe in the Tohoku Bubble Chamber Magnet System

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Each of the two coils contains approximately 80 liters of liquid helium, and each is hard piped to a dewar with a capacity of 1300 ℓ. These 1300 ℓ dewars will be batched filled from commercial 500 liter dewars. Procedures will call for the fill dewars to be disconnected or valved off from the 1300 ℓ dewars when a fill is not taking place. In addition, a fill will only take place when the magnet is not powered. Therefore, the maximum helium available for a single failure is approximately 2800 L. It was demonstrated in the document "Maximum Pressure in the Tohoku Bubble Chamber Magnet System" that the 500 liter Airco supply dewars can never be overpressurized. Thus this volume is not considered to be part of a single failure accident.

Lab E and Lab F have a combined volume of 450,000 ft^3 with a height of 27-1/4 ft. The mezzanine is 14-1/4 ft above the main floor and the floor is 5'8" below ground level. Lab E is bare of ductwork and intake fans. It has a single 10,000 SCFM exhaust fan mounted in the roof. Normally fresh air in Lab E comes through Lab F. There are four air handling units in Lab F which circulate 9700 SCFM of air. Of this 9700 SCFM a minimum Of 15% or 1455 SCFM is fresh air. Two small areas - the oil pump room and the transrex room - have their own intake and exhaust fans. These rooms will normally be closed off from the main part of Lab F and will have minimal effect on the remainder of the building.

Liquid helium poses a possible ODH problem to Lab E and Lab F. Only single LHe failure will be considered and not combined LHe + LN_2 or LHe + Freon failures. The relatively limited amount of helium (2800 L or 74500 SCF) and the large size of the labs mitigate the consequences of a possible helium release. If the total 2800 liters were released, the helium could totally inert the top 4-1/2 feet of both buildings. People are normally not working at this elevation. This case might crudely approximate a catastrophic rupture of both liquid helium systems. At a much later time the helium could diffuse uniformly through the combined labs creating an atmosphere with a PO_2 level of 133 mm. A marginal ODH situation would be present. It would depend on the leakage rate of helium from the building. Any major release of helium into Lab F would be immediately obvious.

Since either concentrated helium or uniformly dispersed helium present a possible ODH, the probability of a fatality must be addressed as per Fermilab's 15.1 Safety Standard.

$$\phi = \Sigma P_i F_i$$

where

ϕ = ODH index (hr^{-1})

P_i = the probability of the i^{th} event hr^{-1}

F_i = the fatality factor of the i^{th} event

for ODH class 0 we need $\phi < 10^{-7}$/hr or less than 1 death per ~ 1000 years.

$F_i = 1$ for $PO_2 < 65$ mm

$= 10^{(6.5 - PO_2/10)}$ for 65 mm $< PO_2 <$ 135 mm

Naturally any calculation of this type should be viewed with much skepticism. Perhaps a feel for the general level of safety can be obtained. The following probabilities are assumed from Fermilab's 15.1 (new draft) document except where noted.

Weld Leak	$3\text{x}10^{-9}$/hr	(1 per 38,000 years)
Rupture of dewar	10^{-6}/hr	(1 per 100 years)
Cryogenic line rupture	$3\text{x}10^{-6}$/hr	(1 per 38 years)
Error of omission from a procedure	$3\text{x}10^{-3}$/day	(1 per year)
General error of commission	$3\text{x}10^{-3}$/day	(1 per year)
*Crane operator error in Lab F	$3\text{x}10^{-2}$/day	(1 per month)
*One side pressurization from a magnet quench	10^{-3}/hr	(~1 per month)
*One side pressurization from catastrophic vacuum failure	10^{-4}/hr	(~1 per year)

*Probability of a rupture = $P_{(\text{rupure of dewar})} + P_{(\text{rupture of interconnecting line})}$

$+ P_{(\text{100 welds in the system})}$

$= 10^{-6} + 3 \times 10^{-6} + 100 \times 3 \times 10^{-9}$

$= 4.3 \times 10^{-6}$/hr (1 per 27 years)

**NOTE: These are my numbers. Failure of the cryostat is part of the 100 weld failure rate. Magnet quench rates assume a maximum frequency of one large quench every 40 days. Actually the coil is never expected to quench as is the design for the CCM. This magnet is fully expected to survive a quench which is not the case for the CCM. Catastrophic vacuum failure is assumed to be operator error and is assumed to occur less than ~ once per year (10^{-4}/hr). Only two methods of catastrophic vacuum failures are conceivable.

1. Violate operating procedures; leave pumpout operator on valve MV/RV-03-V (3×10^{-3}/day) and then open this operator when the magnet is full of helium (3×10^{-3}/day) = 9×10^{-6}/day = 4×10^{-7}/hr.

2. Crane operator error; hit the liquid helium dewar with an object carried by crane with a heavy object (3×10^{-2}/day or once a month), then catastrophically severe a weld (10^{-1} per event) when the system is full of helium (1/2 the time) = 6×10^{-5}/hr.

A 10^{-4}/hr rate was chosen to provide an extra safety factor.

ODH will be based on only one coil failure since the two coils are essentially independent. For example, rupture of pipes and loss of vacuum are independent events from the two sides. Simultaneous coil quenching may or may not be considered a coupled system. By far the most likely failure mode is low LHe level. This almost certainly would not happen in both coils at the same time. Futhermore, once a quench was initiated in one system the interlocks would trip, and the second coil's current would be quickly reduced far below its cold end recovery current level. Thus the probability of a helium release for two systems is only 2 x the probability of one system with 1400 liters rather than ~ (10^{-3} x 10^{-3}) x (4.3×10^{-6} x 4.3×10^{-6}) = 2×10^{-17}/hr (one double failure every ten thousand billion years or until the sun goes out) for a coupled system with 2800 liters where

$10^{-3} \times 10^{-3}$ = probability of two simultaneous magnet quenches

$4.3 \times 10^{-6} \times 4.3 \times 10^{-6}$ = probability of two simultaneous dewar ruptures

It is assumed that system pressurization is required for system failure. That is to say the magnet system will not spontaneously fall apart.

The probability of either side pressurizing followed by a massive rupture is, therefore,

$$2 \times (10^{-3}/\text{hr} + 10^{-4}/\text{hr}) \times 4.3\times10^{-6}/\text{hr} = 9.5\times10^{-9}/\text{hr}$$

$$P = 9.5\times10^{-9}/\text{hr} \text{ (one failure per 10,000 years)}$$

This means that even with a fatality factor F=1 the system is an order of magnitude safer than the required ϕ 10^{-7}/hr for ODH class 0. With this failure rate any conceivable mode of helium spill (i.e. local areas with PO_2 = 0 mm) is an acceptable risk. It also means that any double dewar spill is an acceptable risk.

Because large uncertainties exist in the assumed probabilities, further estimates of the fatality factors and overall level of safety will be made. With only 1400 liters (single dewar) of helium uniformly distributed through Lab E and Lab F, the PO_2 level would be 146 mm (19%). For this case F_i=0. If this volume of liquid were only distributed in Lab F (3.2×10^{5} ft^3), the PO_2 level would be 140 mm (18.5%), and still F_i=0.

The most likely dangerous situation would be a massive helium spill with a person standing on the bubble chamber platform. At this point the persons head would be seven feet from the top of the ceiling. If the rising helium gas cloud were confined to completely inerting down to the seven foot level, it would cover 1/2 the surface area of Lab F. If the gas cloud covered the entire surface area down to the seven foot level, the PO_2 level, would be 87 mm (11.4%). With this O_2 concentration the fatality factor is 0.01. A 50% loss of judgement would be expected, and the individual would have over 10 minutes until loss of consciousness.

Safety is further enhanced by the venting of helium to the outside through the 6" vent lines. All the helium release ODH estimates assume a catastrophic rupture of the inner helium vessel into the vacuum shell which then vents directly into Lab F. It is inconceivable that a rupture could occur at less than 20 psig which is the rupture disk setting for the vent line. Thus large volumes of helium would be funneled outside and cannot contribute to any ODH problem. In any event, the helium cloud would disperse rapidly (~30 seconds) which is most probably not a long enough exposure time to be life threatening. Even at 0% O_2 an individual has ~11 seconds to loss of consciousness. See the attached chart from Fermilab's Technical Supplement to ODH. The only dangerous situation would be for an individual to remain standing on top of a dewar inside the cold helium cloud where he could then fall off. No person who would be in Lab F is expected to be this silly.

Small long term leaks must also be investigated for possible ODH situations. The minimum PO_2 level of ODH class 0 is 135 mm (17.8%). Helium will displace the same fractional amounts of O_2 and N_2. The air being exhausted from Lab F can be allowed to contain 135/159 = 85% of the normal O_2 and N_2 concentrations with the remaining 15% He. Thus Lab F can exhaust a steady state helium leak of 1455 SCFM x 0.15 = 220 SCFM He which is equivalent to a boiloff rate of 500 liter/hr. This is over thirty times greater than the expected normal helium boiloff rate. No ODH is possible from small leaks.

The boiloff helium gas is routed into the control room. All this plumbing is very low pressure. One or two leaking fittings pose no problem. To provide an extra level of redundancy a fan has been installed in the control rack which will permanently purge the control rack into Lab F.

Conclusion:

Lab F should be considered an ODH zero area. Freon must be considered separately, however. The system is estimated to be 10 times less likely to rupture than required by Fermilab's ODH class zero standard. Even if a catastrophic rupture were to occur, a fatality would be very unlikely. Long term small leaks also pose no threat in Lab F.

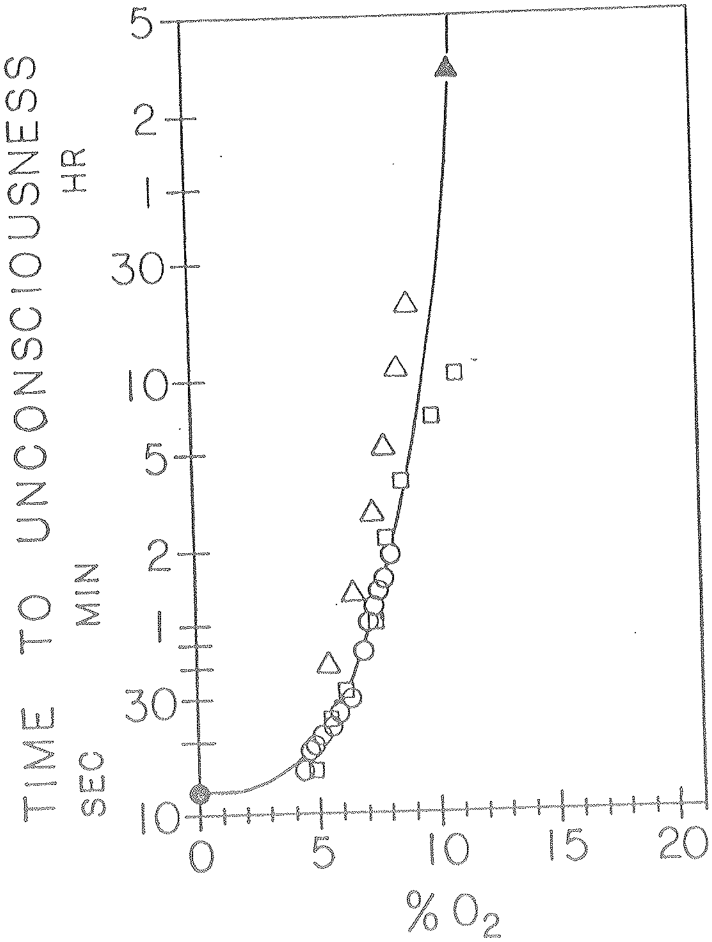

Figure 1 - Approximate time of useful consciousness as a function of oxygen concentration for seated subjects at sea level. □ Duration of useful consciousness. o Duration of useful consciousness. Δ Time to coma. ▲ "Threshold" for unconsciousness. ● Time to unconsciousness.

Technical Supplement to "Oxygen Defficiency Hazards". Provided by FNAL's Safety Office
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